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CONTROLLING THE HAZARD OF METHANE EXPLOSIONS IN COAL STORAGE FACILITIES

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CONTROLLING THE HAZARD OF METHANE EXPLOSIONS IN COAL STORAGE FACILITIES

by

Dr. R.J. Kolada* and Dr. R.N. Chakravorty**

ABSTRACT

Explosions of methane in coal silos and coal ships is an ever present hazard. Recent investigations have shown beyond question that considerable accumulations of methane do occur in coal storage silos and numerous recent explosions in coal transport shipping strongly indicates that the same conditions also exist in ship storage holds. Investigations have shown that the main concentrations of methane occur within the actual coal pile. Within this region normal silo and ship ventilation systems are ineffective. The main line of defence is therefore to exclude potential sources of ignition or to place the coal in an inert atmosphere, or both.

This paper presents the results of a methane survey of all operating silos in Western Canada. These results demonstrate that a serious and widespread hazard of explosion exists. This paper also discusses various methods by which this hazard may be reduced including methods of ventilation, inertization, microbiological control and early warning systems.

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PRÉVENTION DES COUPS DE GRISOU DANS LES ENTREPÔTS DE CHARBON

par

R.J. Kolada* et R.N. Chakravorty**

RÉSUMÉ

Les coups de grisou dans les silos de charbon et les navires charbonniers constituent une menace constante. Des recherches récentes ont montré hors de tout doute que des quantités considérables de méthane s'accumulent dans les silos d'entreposage du charbon, et les nombreuses explosions survenues récemment sur des navires charbonniers indiquent clairement que les mêmes conditions existent aussi dans les cales des navires. Des enquêtes ont montré que le méthane se concentre surtout dans les stocks de charbon mêmes que ne sont pas capables d'aérer efficacement les systèmes courants de ventilation des silos et des navires. Le meilleur moyen de protection consiste donc à éliminer toute source possible d'inflammation et(ou) à entreposer le charbon dans une atmosphère inerte.

Dans le présent document, on présente les résultats d'une étude sur le grisou dans tous les silos exploités dans l'Ouest canadien. Ces résultats montrent que les risques d'explosion sont élevés et répandus. Le document traite aussi de diverses méthodes qui permettraient de diminuer ce risque, notamment des méthodes de ventilation, d'inertisation, de contrôle microbiologique et de systèmes d'avertissement à déclenchement rapide.

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CONTENTS

	Page
ABSTRACT	1
RESUME	iii
INTRODUCTION	1
METHANE ACCUMULATION IN COAL STORAGE SILO	1
METHODS OF ALLEVIATING THE RISK OF METHANE EXPLOSIONS	5
VENTILATION	6
BIOLOGICAL OXIDATION OF METHANE	6
INERTIZATION	11
MONITORING	12
CONCLUSIONS	13
ACKNOWLEDGEMENT	13
REFERENCES	14

FIGURES

No		
1	Actual Methane accumulation within coal silos for a number of washed coals from western Canada. Curves ABDE represent washed metallurgical coal and curve C represents washed thermal coal	2
2	Coward's Triangle showing explosibility of methane, oxygen and nitrogen mixture	3
3	Methane and oxygen concentrations measured within a coal pile superimposed on a Coward's diagram	4
4	Diagramatic Representation of the Silo	9
5	Gas Levels in the Coal Pile during Biological Oxidation Test	10

INTRODUCTION

In recent years there has been an increasing number of explosions and fires within coal transport ships, storage silos and loadout facilities. The threat to property and life from such incidences cannot be overlooked. Consequently, the Surface Mining Laboratory of CANMET have initiated investigations into possible solutions.

This paper presents overwhelming evidence that methane exists in potentially explosive concentrations within coal silos, which is consequently released into the atmosphere of loadout facilities. Since there is little difference in the storage conditions of ships and silos, there is a strong inference that potentially explosive mixtures also exist in coal transportation ships.

This paper also examines the likely causes of ignition in terms of electrical sparks, spontaneous combustion and heated coal or other objects that can enter storage facilities. Possible remedial measures to prevent explosions are discussed. These include methane removal by application of micro-organisms, inertization of the atmosphere of the storage facility, and by installation of automatic methane and carbon monoxide detectors and infrared line scanners.

METHANE ACCUMULATION IN COAL STORAGE SILO

Initial investigations by CANMET (1) at two mine sites in Western Canada revealed that explosive concentrations of methane could accumulate within the voids of the coal pile. This led to the decision to conduct a large scale survey of methane accumulation within as many operating silos as possible (2). This survey confirmed the earlier findings that methane accumulation within the voids of stored coal was a wide spread problem.

Figure 1 shows the percentage methane concentration within the coal pile of silos at different mines. It is important to realize while examining these graphs that methane is flammable or explosive between 5 - 15% by volume in air. For case A the concentration of methane in the silo has risen to 40%

within an hour of filling the silo. Concentrations this high are not flammable since there is not enough oxygen to sustain combustion. However, when the coal is discharged from the silo the methane trapped within the coal pile will be released to the atmosphere in the loadout facility and hence may be diluted through the explosive range.

That methane is flammable in the range 5 - 15% is dependent on the condition that the air with which it is mixed contains the normal level of oxygen. If, for example, the air contained only 15% oxygen instead of the normal 21% (20.9), methane would only be flammable in the reduced range of 5 - 10%. In fact, if air contained only half the normal level of oxygen (10%) methane mixed with air would not be flammable at any concentration.

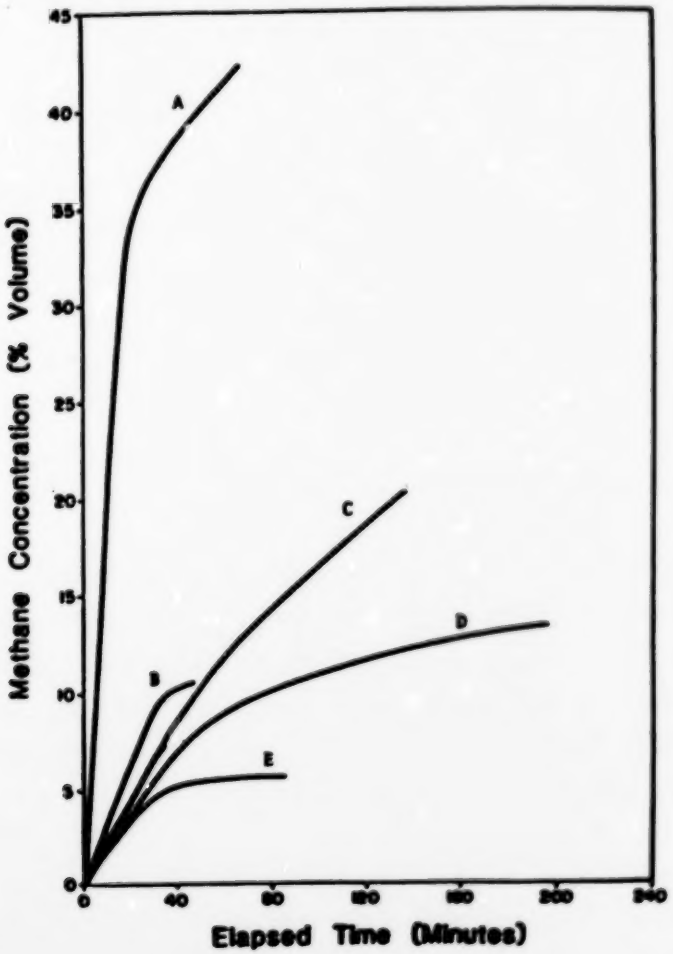

Fig. 1 - Actual Methane accumulation within coal silos for a number of washed coals from western Canada. Curves ABDE represent washed metallurgical coal and curve C represents washed thermal coal.

This relationship between the concentrations at which methane is flammable in air of different oxygen concentrations is best illustrated by a "Coward triangle" as shown in figure 2. The area within the triangle are those gas mixtures that are flammable or even explosive. This relationship is important due to the fact that fresh coal absorbs oxygen from the atmosphere. This absorption of oxygen is usually at a very slow rate and the heat produced is small. Consequently, the temperature of the coalpile is normally not much greater than ambient. However, it is important to note that if this quantity of heat cannot escape, the rate of oxidation will increase and so will the heat produced until the coal bursts into flame.

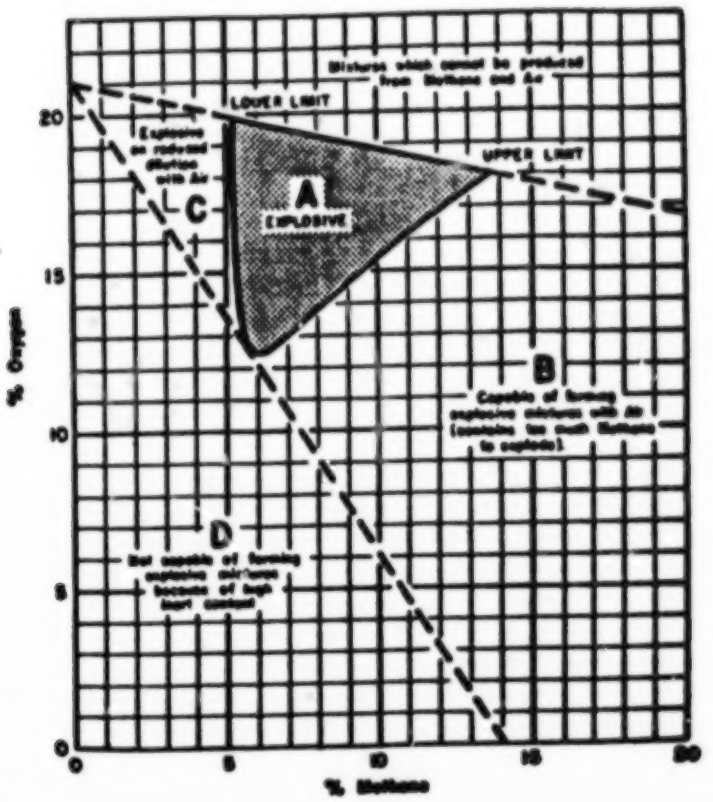

Fig. 2 - Coward's Triangle showing explosibility of methane, oxygen and nitrogen mixture.

In coal storage silos, oxygen is absorbed from the air trapped in the coalpile. Therefore, the oxygen content, as well as the methane content, must be measured in order to calculate whether the gas mixture is explosive. Figure 3 shows a plot of the methane and oxygen concentrations measured within the coalpile of a silo. The measurements were taken over a period of two hours starting from the time that the end of the sample tube was buried under the incoming coal stream. The range of oxygen and methane concentrations passed through a number of distinct stages. Initially there is zero methane and the normal level of oxygen found in the atmosphere. The oxygen concentration then decreases as it is adsorbed by the coal and the methane concentration starts to rise as methane desorbs from coal.

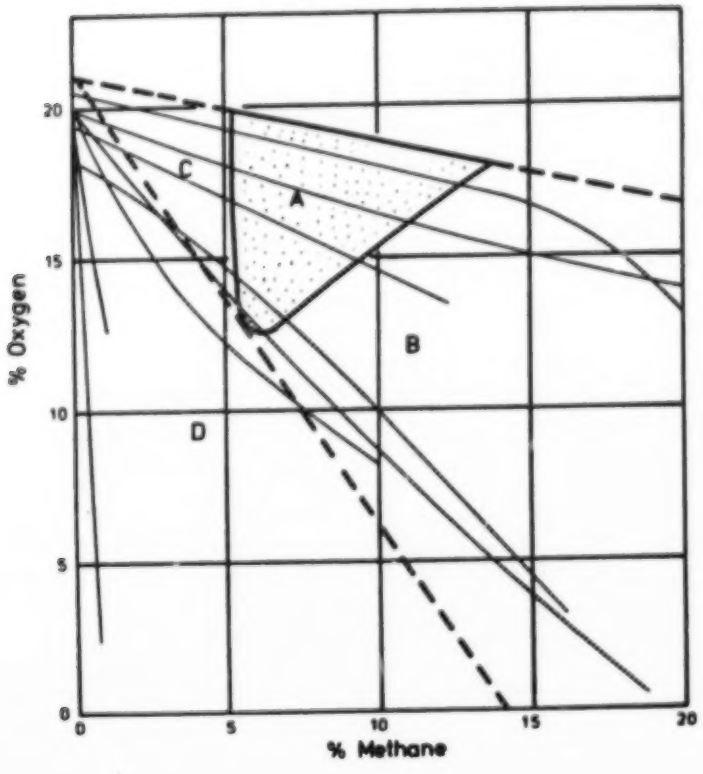

Fig. 3 - Methane and oxygen concentrations measured within a coal pile superimposed on a Coward's diagram.

Within the region D there is insufficient oxygen to sustain combustion with the given concentration of methane. Also, even if air were to be added to the mixture it would still be impossible to make the mixture flammable as this would dilute the concentration of methane to below the flammable limit.

In region C there is still not enough methane to be flammable. However, if methane were added to the mixture it would pass through the flammable zone.

Region B is similar to C but instead of too little methane, it has too much. This mixture will pass through the flammable region if air is added.

As can be seen from figure 1, the gas trapped in the coal pile after two hours was not explosive since the concentrations lay in region B. However, if the silo were to be opened and the coal discharged, then the trapped gases would be diluted by the surrounding atmosphere and would therefore have to pass through the flammable range.

Figure 3 is similar to figure 2 but shows the gas concentrations found in all of the silos tested. From this graph, there are two obvious trends; namely, a decrease in oxygen content and an increase in methane concentration. Often the gas mixtures do not remain within the flammable range for very long and occasionally even bypass the flammable range completely. However, in 50% of the cases examined, the gases within the coal pile will pass through the explosive range upon dilution with air. This situation will likely occur within the loadout facilities of coal silos and is therefore an area of some concern.

METHODS OF ALLEVIATING THE RISK OF METHANE EXPLOSIONS

Methods to completely eliminate the risk of methane explosions in coal storage facilities do not yet exist. However, research into the biological oxidation of methane may come close to eliminating the problem and this will be discussed in some detail later in this paper. Until these new technologies are developed, existing methods of reducing the risk of

methane explosion will have to be adopted. To reduce the risk to a minimum, several, or all of the methods described below may be used in conjunction with each other.

VENTILATION

Silos and ship holds all use some form of ventilation to remove any methane that accumulates in the atmosphere above the coal pile. This may be achieved by natural ventilation where wind currents from outside the storage facility are allowed to blow across the coal pile. Alternatively artificial ventilation using electric fans may be used. Artificial ventilation has the advantages of greater control over the rate of ventilation and of reducing coal dust emissions. Without ventilation of the atmosphere above the coal pile methane would accumulate within this region. This could happen in two ways. One, by simply increasing the general body methane concentration of the atmoshpere. Secondly, by forming a layer of methane of high concentration at the roof of the storage facility as a result of its natural buoyancy (methane's density is half that of air's). A survey of methane concentrations in all operating coal silos in Western Canada revealed that all silos had insignificant methane concentrations in the atmosphere above the coal even though very high concentrations existed within the voids of the coal pile. Due to these investigations, methane accumulations within this region does not constitute the most significant hazard.

BIOLOGICAL OXIDATION OF METHANE

Earlier discussions have indicated that with coal storage silos, ventilation of the head space alone may not be effective for controlling the risk of a methane explosion. Explosive concentration of methane can occur within the coal pile inspite of vigorous forced ventilation above the pile.

The potential use of biotechnology to remove and degrade methane within the coal pile is receiving much attention in Canada. The technique involves the application of methane oxidizing bacteria to the coal before storage in order to oxidize methane released by the coal into non-flammable products.

Earlier work in Canada and abroad [3] indicated that micro-biological control of methane is feasible. The chemical transition of methane via bio-oxidation to non-flammable carbon dioxide is given below:

$$CH_4 \rightarrow CH_3OH \rightarrow CH_2O \rightarrow CHOOH \rightarrow CO_2$$

The overall reaction can be summarized as:

$$CH_4 + 2O_2 = CO_2 + H_2O$$

(flammable) (non-flammable)

Initial laboratory research [3] has shown that it is possible to isolate methane oxidizing bacteria from coal and water samples from various mines in Canada. Laboratory studies have also indicated that the rate of methane oxidation by these bacteria can be quite appreciable. In a laboratory test flask, it was found possible to oxidize a 10-20% methane concentration within 24 hours.

Only aerobic bacteria was cultured for this study which requires the presence of molecular oxygen before the bacteria can oxidize methane to carbon dioxide. The availability of oxygen is therefore a controlling factor on the amount of methane that can be oxidized. For a successful application of this technique to reduce or remove methane from coal piles in storage facilities, it is essential that bacterial activity be maintained for the period of time that the coal is stored. Laboratory results indicate that almost 60% of the original activity is retained after a period of 100 days when applied to low sulphur coal.

Small laboratory experiments were successfully scaled up to allow a 10 kg sample of coal to be tested in a model silo and the rate of oxidation was found to be suitably encouraging as to warrant further examination. It also became evident that in all of the experiments the amount of oxygen present is a controlling factor in determining the amount of methane oxidized.

The strains of methane oxidizing bacteria used for this study were characterized in terms of their pH and temperature versus activity profiles. The optimum temperature for bacterial activity were found to be 33 degrees Centigrade. The activity dropped rapidly when the temperature was raised above this optimum, but only dropped slowly when it was lowered. The organisms were found to be inactive at temperatures below -20 and above 40 degrees Centigrade. However, they regained their activity once the temperature was readjusted to more favourable values.

Scaled up tests are being conducted at present in a model silo 3 metres tall and 1.2 metres in diameter [4]. Sampling ports are installed at 0.3 metre intervals into the side of the silo as shown in figure 4. Tests were conducted in the model silo using washed coal from both Eastern and Western Canadian mines. Results of these tests show that when treated with bacteria there is a rapid consumption of oxygen with production of carbon dioxide and a significant drop in methane concentrations.

Using this model the bacterial oxidation phenomenon was studied under three different conditions. The results are illustrated on figure 5. With the silo top closed there is a large increase in methane concentration within the coalpile and in the head space above the coalpile. The build up in the head space is expected since there is no ventilation. The build up within the coalpile is also high due to the silotop being closed since this prevents the replenishment of oxygen once it has been depleted by the bacteria. In tests where the top of the silo was left open to the atmosphere about 2-3% of residual methane was found within the coalpile. This was due again to insufficient oxygen supply to the bacteria. If however the head space is forcibly ventilated with a fan, oxygen can penetrate to a depth of several metres resulting in considerably reduced levels of methane. With large piles of coal penetration of oxygen to a few metres is likely to be inadequate, requiring air injection into the pile. Further research will be necessary to develop coalpile air injection techniques.

Surface spraying of the bacteria onto the coal before storage would seem to be the simplest method of application. Plans are now underway to carry out tests on larger models capable of holding 80 tons of coal.

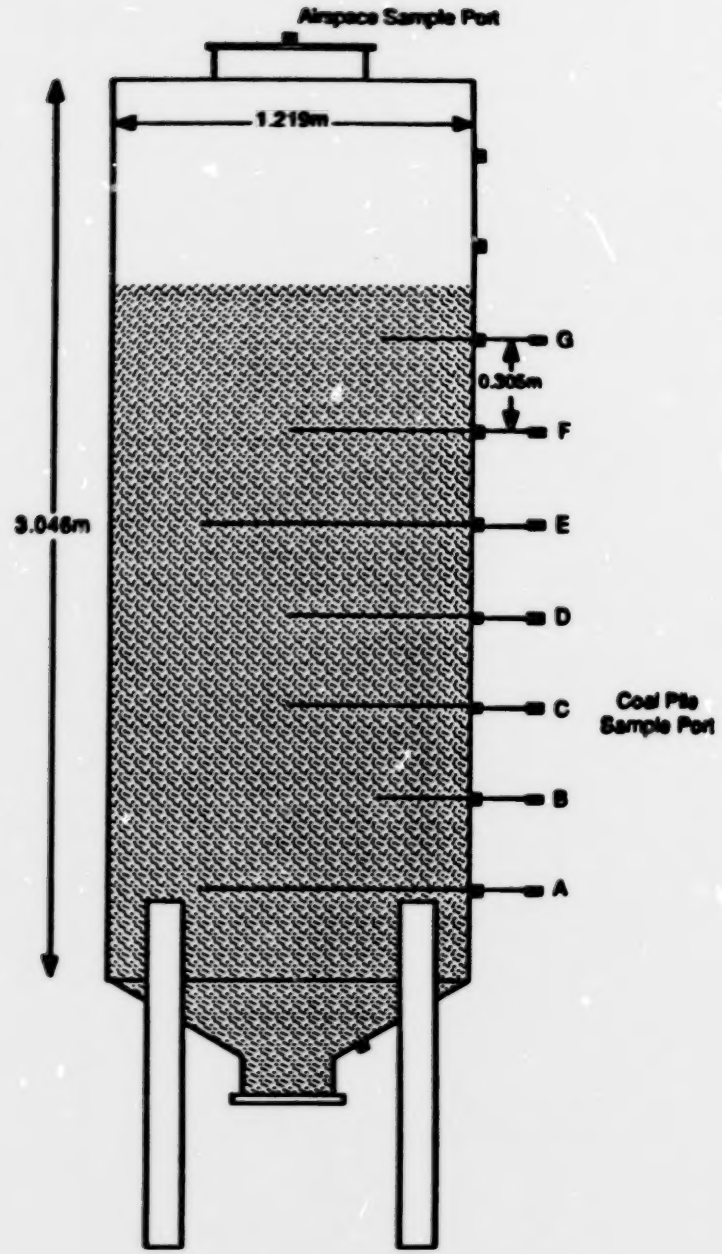

Fig. 4 - Diagramatic Representation of the Silo.

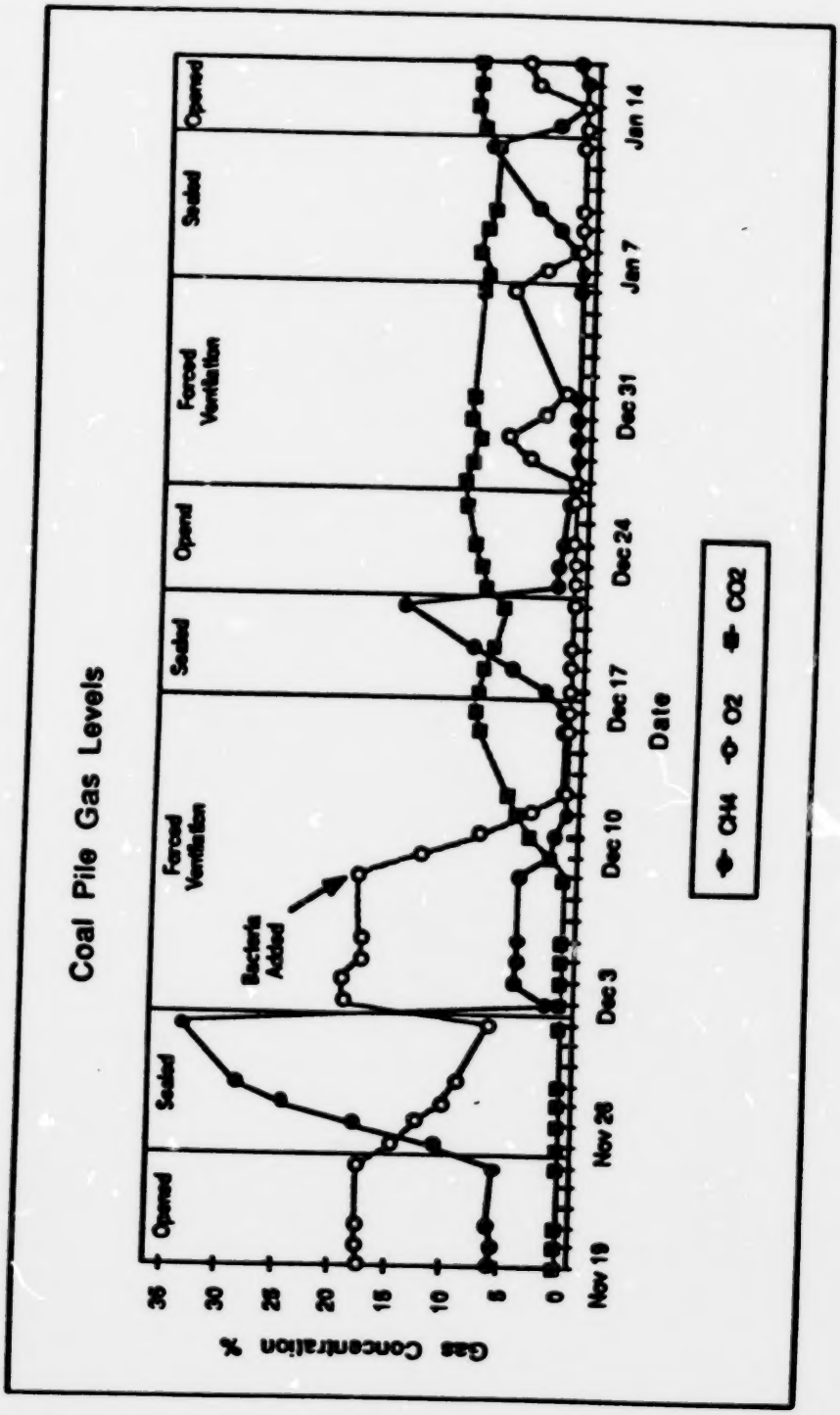

Fig. 5 – Gas Levels in the Coal Pile during Biological Oxidation Test.

INERTIZATION

The principle of inertization is to deprive methane released by coal the opportunity to mix with sufficient oxygen to become explosive. By examination of the "Coward Triangle" diagram on figure 2, it can be seen that if the concentration of oxygen within an air methane mixture is reduced to 12% or less, then no amount of methane will cause the mixture to become explosive (unless of course additional air is also added), i.e. the mixture is inert.

In recent years major advances have been made in the use of inertization to control mine fires and explosions. In most applications to date nitrogen has been the "choice of preference" as an inerting gas for diluting the oxygen content of hazardous atmospheres within mines. However, carbon dioxide and generators that produce oxygen free exhaust gases have also been used to good effect. The fact that carbon dioxide is heavier than air makes it particularly suitable for inerting atmospheres in coal piles where a heating due to spontaneous combustion has occurred at depth. A number of mine operators in Canada have now installed CO_2 tanks close to their silos expressly for this purpose.

Gas generators may also find application for inerting surface coal storage facilities. They usually consist of a modified jet engine with an after burner. The inert combustion products are passed through a cooler and discharged through a duct to the fire area. The inert gases generated by this method are cheaper than others but it has the problem of removing the heat it generates when used underground. This disadvantage will obviously not be a problem for above ground applications such as storage facilities. Consequently, it is expected that their use will become more common in the future.

MONITORING

One of the primary defences in the mining industry against the threat of explosion or fire is the installation and vigilant use of a good monitoring system [5]. Coal storage facilities should be no exception. The results of the methane survey already described indicate that the head space above the coal pile, if moderately ventilated, should be free of concern regarding methane accumulation. However, there can be a serious build up of methane within the coalpile. The concentrations of methane within the coalpile can be explosive. Alternatively, they can be potentially explosive upon dilution with air, as occurs upon discharge from the silo. A consequence of this fact is that monitoring of methane in the discharge gallery and loadout facility is equally and probably more important than monitoring the atmosphere above the coalpile.

In addition to detecting the presence of an explosive gas concentration it is also important to prevent the occurrence of ignition sources. The underground coal mining industry has of course a great deal of experience in such matters. If the storage facility is a high risk then consideration should be given to treating the area in the same manner as an underground coalface. Some of the more important measures include: flame proof electrical equipment, good ventilation and a reliable methane monitoring system in the discharge and loadout areas.

It is also possible to detect two of the more common sources of ignition. The first is hot coal and other objects delivered from the dryer along the conveyor and into the silo. The second is spontaneous combustion within the coalpile to which low rank coals are particularly susceptible. Hot coals or other objects on a conveyor may be detected with infra-red equipment and can be programmed so that the conveyor will be stopped automatically. The line scanning type of infra-red equipment is particularly suitable for this purpose. They can detect the temperature of small objects from a distance and operate at a speed compatible with the number of coals that will pass a given point on a conveyor.

Spontaneous combustion produces carbon monoxide as a product of low temperature combustion. There exist a number of sensors capable of testing this gas and can be incorporated into existing monitoring system. If abnormal levels of CO are detected the use of inertization is perhaps the best approach.

CONCLUSIONS

The main conclusions are as follows:

1. The methane survey of operating silos in Western Canada indicates that methane accumulations in the atmosphere above the surface of the coal pile is rarely a source of concern. However, even though safe levels may exist above the coalpile, high and potentially hazardous concentrations can exist within the coalpile.

2. There exists a number of techniques that may combat the hazards associated with high methane concentrations within the coalpile. These include: Oxidation of methane with aerobic bacteria: Inertization of methane gas mixtures by dilution of the oxygen content with an inert gas: Monitoring of the storage environment to detect and avoid potentially hazardous situations.

3. Although biological control is in its infancy, it may prove to be a superior method of methane control. Inertization and monitoring however, are techniques that are currently available and are proven to reduce the risk of explosion.

ACKNOWLEDGEMENT

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